CONSTRUCTION, ASSEMBLY, AND INSTALLATION OF THE ASTA FRONT-END DIAGNOSTIC TABLE*

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Abstract

The Advanced Superconducting Test Accelerator (ASTA) is housed in the NML building at Fermilab. The ASTA Front-End is a high brightness, 1.5 cell, copper, 1.3 GHz RF Gun that accelerates electrons with a ~40 MV/m gradient. The Diagnostic Table is a part of the ASTA Front-End and is responsible for directing the ultra-violet (UV) laser to the photocathode and providing instrumentation for studying the electron beam, akin to the DESY FLASH design.

INTRODUCTION

The ASTA Front-End generates high brightness electron bunches with a 264 nm UV laser that illuminates a cesium telluride (Cs_2Te) photocathode on the upstream wall of the 1.5 cell copper RF Gun operating at 1.3 GHz. A Diagnostic Table is immediately downstream of the RF Gun. Figure 1 shows the layout of the ASTA Front-End. The table contains 2 beam crosses (a 9-way cross and a 6-way cross), 2 trim dipole magnets, 2 cameras with associated lens tube hardware, 2 sets of horizontal and vertical beam position monitors (BPM), 2 100 liter/s ion pumps, a Laser Injection Light Box, and a Wall Current Monitor.

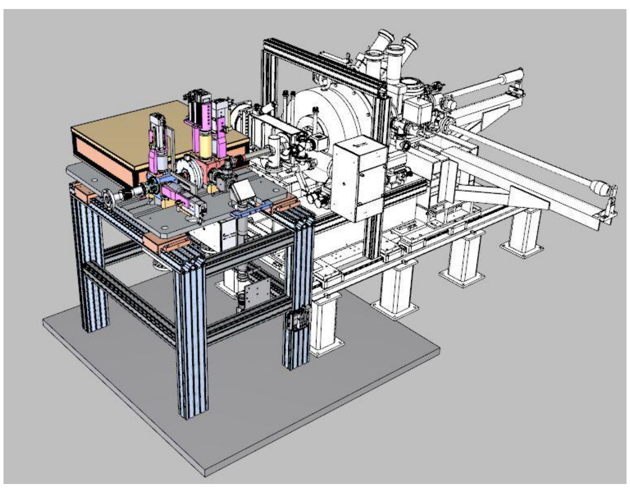

Figure 1: 3D model of the ASTA Front-End. The Diagnostic Table is shown with color.

The 9-way Cross provides many functions. The upstream east window has a coated fused-silica window to allow the 264 nm UV laser to enter the vacuum system and reflect off a polished aluminum mirror, directing it to the photocathode inside the RF Gun. A mirror can be inserted via an actuator to direct scattered UV out of the vacuum system and to a CCD camera attached to the upstream west side coated fused-silica window. This will provide a picture of the photocathode surface. A double actuator is mounted on the downstream end of the cross and moves a dual position holder contained in the edge-welded bellows. The first position inserted into the cross is the target, a piece of fused-silica glass 19 mm in diameter with concentric circles 1 mm apart. An LED inside the lens tube, affixed to the downstream west side of the cross, illuminates the target and allows the focus to be set on the networked camera connected to the lens tube. The next position in the holder is the 25.4 mm diameter cerium doped YAG crystal. Since the target and the crystal are in the same plane, the camera does not require any re-adjustment. Photoelectrons deposit their energy into the crystal, causing it to scintillate. The light is reflected to the CCD camera where the spot size is measured and transverse dimensions of the electron beam are calculated. A 3D CAD representation of the 9-way Cross is shown in Figure 2.

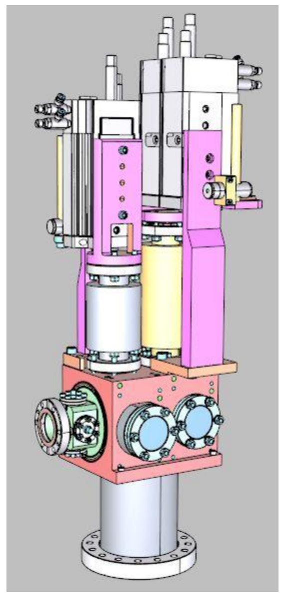

Figure 2: 3D CAD model of 9-way Cross

The 6-way Cross contains one vertically mounted actuator and one horizontally mounted actuator. The vertical actuator inserts an electron beam collimator, a piece of copper with a 10 mm diameter hole through it. This will be used to collimate the electron beam if the dark current is too large and inducing quenches downstream. The horizontal actuator is used for inserting a Faraday Cup into the beam path. Only one device can be inserted at a time since the collimator and Faraday Cup operate at the same z-position. Collision bars are affixed to the actuators in the event that an “in” command is issued to both. Figure 3 illustrates the layout of the 6-way Cross.

Two sets of horizontal and vertical 5V, 10A corrector trim dipole magnets are attached to the upstream spool piece. These trims allow for the horizontal and vertical steering of the photoelectron beam through the crosses.

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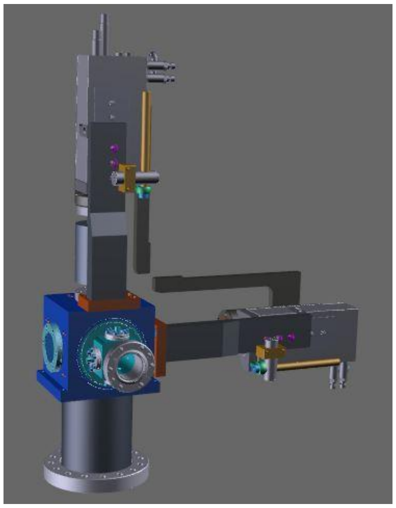

Figure 3: 3D CAD model of the 6-way Cross.

Each cross has a housing for horizontal and vertical button BPMs. The BPMs are located on the upstream side of the 9-way Cross and on the downstream side of the 6-way Cross.

There is one 100 liter/s ion pump connected to each cross. They are located under the table. The 6-way Cross ion pump also contains the interlocked vacuum switch for the UV laser safety system, the convection and cold cathode gauges, and a turbo pump out port.

The Laser Injection Light Box is used for directing the 264 nm UV laser into the 9-way cross vacuum chamber and onto the Laser-In mirror. The base of the box is an optical breadboard. On the board are pico-motor mirror mounts that direct the laser's path and are tunable through the ACNET control system. The box must be light tight and the top of the light box is secured with a Laser Safety Officer's lock.

A Wall Current Monitor (WCM) is used for determining the longitudinal profile of the photoelectrons from the RF Gun. A ceramic break allows the electron beam's image charge to be measured by the WCM. The signal is seen on a fast sampling scope in a relay rack outside of the ASTA beamline enclosure.

CONSTRUCTION AND ASSEMBLY

Because ASTA uses Superconducting RF cavities for electron beam acceleration downstream of the Front-End, all components connected to the ultra-high vacuum system are required to be cleaned, assembled, and installed in cleanrooms using particle free techniques. Once each cross assembly is completed, 2.75" blank flanges are installed on the upstream and downstream beam tubes. The assemblies are then vacuum leak checked with helium.

9-way Cross

The 9-way Cross is constructed entirely from 316L stainless steel. The BPM housing and inner sleeve were welded to the cross. The vacuum port flange is a 6" conflat (CF) and the BPM flanges are 1.33" mini-CF. All other flanges are 2.75" CF.

The heavily machined crosses contain several blind threaded holes. Fastener hardware for the crosses is all metric and made of titanium type 2 rolled threads or silicon-bronze.

Laser-In Mirror Assembly

The Laser-In mirror assembly connects to the upstream east side of the 9-way Cross. A 264 nm UV laser, generated in the adjacent Laser Room, enters the ASTA beamline enclosure and is directed to the Laser Injection Light Box on the Diagnostic Table. The UV laser exits the box and enters the 9-way Cross through the specially coated fused-silica window. The coating on the window allows for a transmission of 96.29% of the laser. The laser reflects off of the aluminum mirror and strikes the photocathode 982.63 mm upstream.

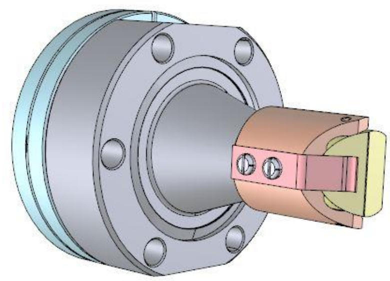

Figure 4: 3D CAD model of Laser-In mirror assembly.

The mirror holder is constructed of 316L stainless steel. When the mirror is inserted into the holder a beryllium-copper spring is affixed with two screws which provide the appropriate tension to keep the mirror in place.

This is a double flange assembly requiring 2 copper gaskets. The mirror holder is integrated into one flange and the window is the other. Installation requires six 50 mm long threaded studs.

Cathode Viewing Mirror Assembly

The Cathode Viewing Mirror assembly is comprised of a 25 mm diameter X 4 mm thick aluminum mirror, mirror holder, actuator-flange, actuator, fused-silica window, 50 mm travel edge-welded bellows, lens tube, and CCD camera. Figure 5 shows the 3D model of the Cathode Viewing Mirror assembly.

When an image of the photocathode is needed, the Cathode Viewing Mirror can be inserted into the 9-way Cross via a pneumatic actuator on the cross. The RF Gun pulse will be inhibited due to the mirror being placed in the beam path. Scattered UV light from the photocathode is directed out of the 9-way Cross and to a 5 megapixel networked GigE camera, sensitive to UV frequencies, for inspection.

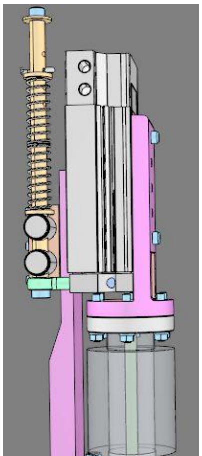

Figure 5: 3D CAD model of the Cathode Viewing Mirror assembly.

The holder is machined from 316L round stock and the fastening hardware is titanium screws. The screws used for connecting the holder to the actuator-flange are vented, as required, so as not to trap any gas in the vacuum system. The actuator-flange is also made from 316L round stock and is fastened to the actuator.

The mirror face has a 25 mm diameter aluminum coating on a 4 mm thick substrate of fused-silica. The mirror surface is enhanced to efficiently reflect UV. Three screws hold the mirror in place on the holder.

The Cathode Viewing Mirror assembly is vertically mounted to the upstream end of the 9-way Cross with six titanium studs and silicon-bronze nuts. A specially coated fused-silica window, identical to the Laser-In mirror window, is located at the upstream west side of the cross. The window is connected with similar hardware as the Cathode Viewing Mirror assembly. A 3” lens tube with an internal O-ring 1/8” thick is placed over the window. The O-ring makes a light tight seal around the window flange. The lens tube has a c-mount adapter attached to it for connecting the CCD camera.

Target and YAG Assembly

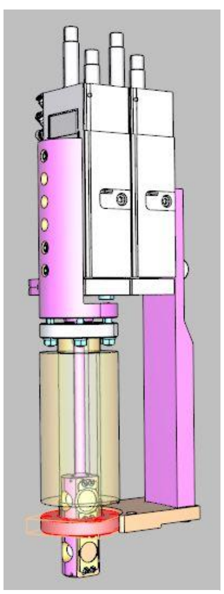

Figure 6: 3D CAD model of Target and YAG assembly.

The Target and YAG assembly consists of a 19 mm diameter x 1.5 mm thick fused-silica glass reticle with concentric circles 1 mm apart and a line thickness of 25 μm wide, a 20 mm diameter mirror, a 25.4 mm diameter cerium doped YAG crystal 100 microns thick, 25 mm diameter mirror, a device holder, an actuator-flange, an actuator, a 100 mm travel edge-welded bellows, a CCD camera with attached lens tube, and a 2.75” fused-silica window. Layout of the Target and YAG assembly is seen in Figure 6.

The device holder is machined from 316L stainless steel round stock. A bracket holds the mirrors in place. Collars secure the Target and YAG to the device holder. The fastening hardware is titanium button head screws. The holder connects to the actuator-flange with 3 vented titanium screws. The actuator-flange is also made from 316L round stock and is fastened to the actuator with cap screws.

The Target and YAG assembly is vertically mounted to the downstream end of the 9-way Cross with six titanium studs and silicon-bronze nuts. A 2.75” fused-silica window is connected to the downstream west side of the cross. A 1/8” thick O-ring is placed over the window flange to provide a light tight seal to the optics tube arm. A 5 megapixel GigE camera is connected to the end of the optics arm.

6-way Cross

Just like the 9-way Cross, the 6-way Cross is constructed entirely from 316L stainless steel. The BPM housing and inner sleeve are located on the downstream end of the cross. The vacuum pumping port flange is a 6” CF and the BPM flanges are 1.33” mini-CF while all other flanges are 2.75” CF.

Fastener hardware for the cross is all metric and titanium type 2 rolled threads or silicon-bronze. Actuator assemblies are connected to the cross with silicon-bronze socket head cap screws.

Faraday Cup Assembly

The Faraday Cup is constructed from oxygen-free high thermal conductivity (OFHC) copper with dimensions of 1”W x 1.75”H x 0.5”T. The Faraday Cup holder is machined from 316L stainless steel round stock. In order to isolate the Faraday Cup from ground, two ceramic stand-offs are connected between the holder and the cup. The Faraday Cup signal is directed out of the ultra-high vacuum system by means of a stainless steel wire with a diameter of 0.51”. The wire is secured to the copper with a 316 stainless steel 4-40 thread ¼” length socket head cap screw. The formed wire is fastened to a copper-beryllium barrel connector. The opposing side of the connector is secured to the actuator-flange feed-through. Figure 7 shows the Faraday Cup during assembly in the cleanroom.

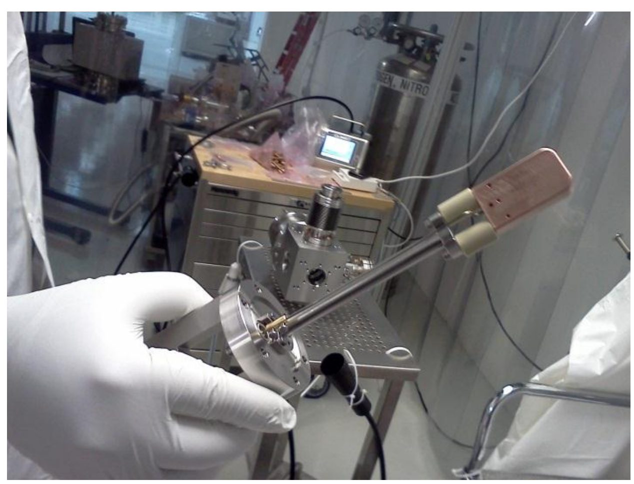

Figure 7: Faraday Cup assembly prior to attachment of the edge-welded bellows.

Collimator Assembly

The Collimator construction is identical to the Faraday Cup except that there is a 10 mm diameter hole through the OFHC copper. Assembly of the Collimator is, also, identical to that of the Faraday Cup. Figure 8 shows the Collimator assembly in the cleanroom.

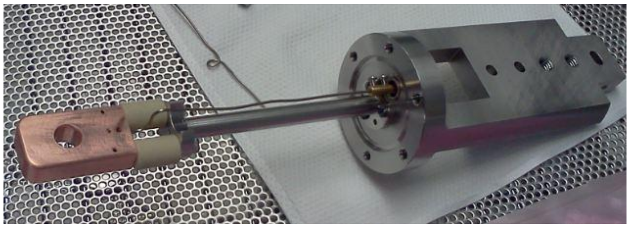

Figure 8: Collimator assembled in the cleanroom, less the edge-welded bellows.

Wall Current Monitor

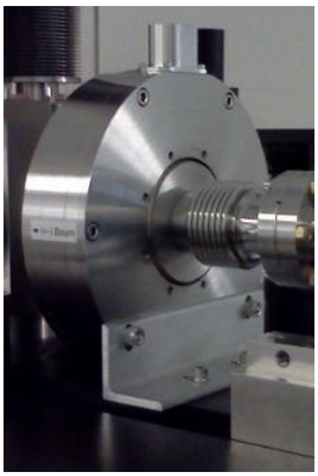

Figure 9: Wall Current Monitor installed on Diagnostic Table.

The Wall Current Monitor housing is machined from 316L stainless steel. The housing is low impedance and frequency tight in order to shield the output signal from ground currents. At the heart of the WCM is a ceramic break made from alumina (Al_2O_3) and Kovar. The ceramic is sandwiched between two Kovar sleeves and brazed together. A circuit board is attached across the Kovar and the output is directed to an SMA connector. A high permeability ferrite ring surrounds the ceramic break and forces the electron beam's image charge through the circuit board's resistors. The ends of the ceramic break are welded to the end flanges of the WCM. Figure 9 shows the Wall Current Monitor installed on the Diagnostic Table.

Trim Dipole Magnets

Four trim dipole (pair) magnets are located on the upstream side of the Diagnostic Table. The magnets are comprised of copper wire wound around an iron core, which are then placed on a machined aluminum corrector coil magnet mount. The upstream pair of trim magnets, H100 and V100, are installed next to the downstream flange of the RF Gun vacuum gate valve. Magnets H101 and V101 are located on the 9-way Cross BPM flange. Figure 10 shows the trim magnets installed around the beam tube. The horizontal and vertical fields are independently adjusted with remotely controlled power supplies located outside of the ASTA enclosure.

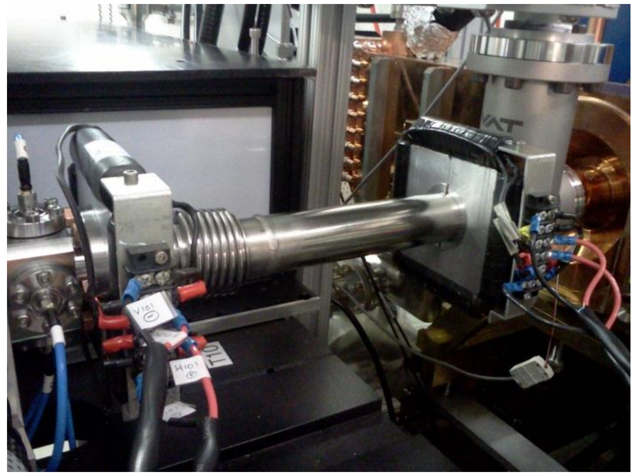

Figure 10: Trim dipole magnets installed on upstream side of Diagnostic Table.

Laser Injection Light Box

The Laser Injection Light Box is constructed from black anodized extruded aluminum, panels of double-sided aluminum with a corrugated plastic core, and a black anodized aluminum ¼"-20 holed breadboard. It is secured to the east side of the Diagnostic Table. The 264 nm UV laser vertically enters the box by way of an ABS plastic tube. The laser is bent horizontally and directed to the Laser-In mirror. Fine adjustment of the UV laser on the photocathode is made with a mirror mounted to a remotely controlled, high-resolution, compact, motorized positioner. Figure 11 shows the Laser Injection Light Box with the cover and the ABS plastic transport tube removed.

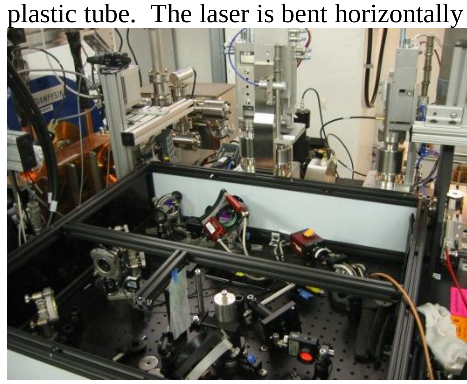

Figure 11: Laser Injection Light Box with cover and ABS plastic transport tube removed.

Beam Position Monitors

There are 2 horizontally and 2 vertically mounted button BPMs on each cross. The body of the BPM is a 1.33" mini-CF flange made of 316L stainless steel. The beam position pickup is 316L stainless steel, the electrical feed through is constructed from molybdenum, and the electrical isolator is alumina. An SMA connector on the top of the flange has its gold-plated beryllium-copper center contact pin laser welded to the molybdenum feedthrough. A copper canted coil spring keeps the flange grounded to the cross. Figure 12 shows the BPM pickup attached to the flange.

Figure 12: Button BPM prior to installation.

INSTALLATION

Once the assembly of the 9-way Cross, 6-way Cross, WCM, and vacuum system was completed, the Diagnostic Table was lifted into the ASTA enclosure. The stand was secured to the floor, vacuum connections were made to the RF Gun within a portable cleanroom, pneumatics were connected, and the Laser Injection Light Box was installed. Figure 13 shows the Diagnostic Table after installation.

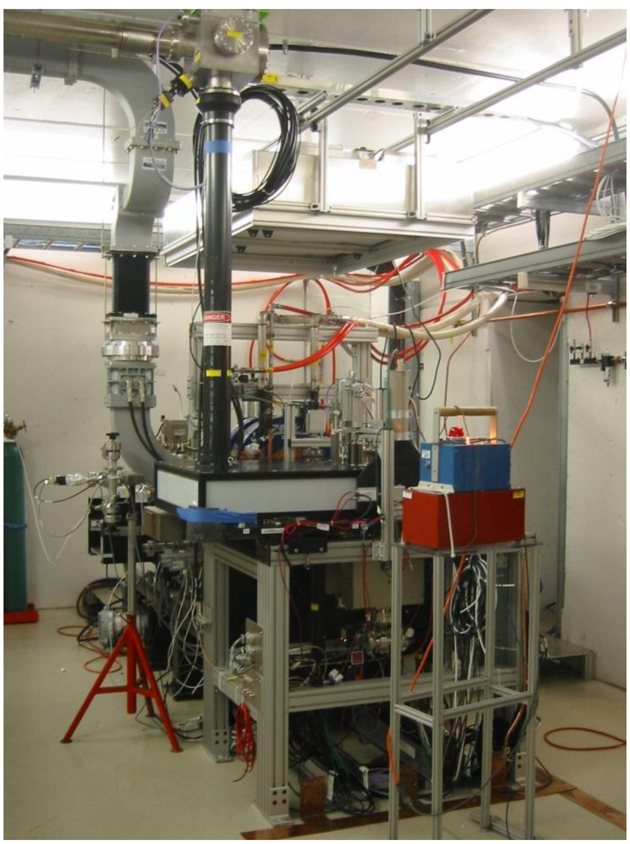

Figure 13: Diagnostic Table fully assembled in the ASTA enclosure.

SUMMARY

Assembly of the Diagnostic Table began on October 4^{th}, 2012 and installation as completed by June 11^{th}, 2013. Once all instrumentation was calibrated and connected to the control system, power was applied to the RF Gun. First UV laser light was established to the photocathode at 11:45 am on June 20^{th}, 2013 followed by first detected photoelectrons at 4:00 pm.

The YAG crystal has been utilized in energy measurements of the photoelectrons at various RF Gun gradients. WCM charge calculations are in agreement with Faraday Cup current measurements. Beam based alignment of the RF Gun solenoid magnets, utilizing the BPMs, will occur as downstream component installation schedules allow.

REFERENCES

[1] M. Church, "Design of the Advanced Superconducting Test Accelerator," Fermilab Accelerator Division Document Database, Beams-doc-4212, November 2012; http://beamdocs.fnal.gov/AD/DocDB/0042/004212/005/ASTA_technical_description.pdf.